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MATERIALS FOR OIL SPILL CONTAINMENT BOOM

By

Donald E. Brunner

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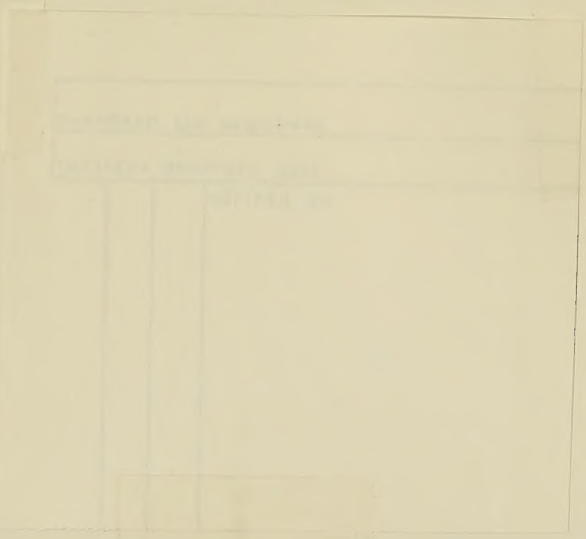

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A study was recently conducted at the Civil Engineering Laboratory to investigate containment boom material requirements, which were defined and weighted in terms of their relative importance. When available, standard test procedures for use in evaluating each requirement were identified. Both substrate materials and coatings to be applied are discussed in this report. From the limited investigation,

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A study was recently conducted at the Civil Engineering Laboratory to investigate containment boom materials requirements, which were defined and weighted in terms of their relative importance. When available, standard test procedures for use in evaluating each requirement were identified. Both substrate materials and coatings to be applied are discussed in this report. From the limited investigation, polyester was the most promising substrate material, followed by nylon. Chlorosulfonated polyethylene, polyurethane with a polyether base, chlorinated polyethylene, and poly(vinyl chloride) formulated with ultraviolet inhibitors are the most promising coating materials. One substrate and coating combination could not be identified as best because of the variation in material properties.

SUMMARY

This investigation was to determine the technical suitability of various materials for use in oil spill containment booms. Containment boom material requirements were defined and weighted in terms of their relative importance and standard test procedures for use in evaluating each requirement were identified. The investigation was directed at synthetic, coated fabrics. A discussion of fabric weaving techniques and methods for applying coatings is included. Information on the properties of available fibers and coatings is presented and those exhibiting the most promising characteristics identified. Some of the coated fabrics currently being used in containment booms and other material composed of promising fabrics and coatings were examined in terms of the requirements previously defined for containment booms.

As a result of this investigation it is concluded that:

(1) The properties required in boom material apply to all booms intended for in-harbor use although the value of certain mechanical properties such as break strength are dependent on boom design.

(2) Mechanical properties of break strength, elongation, flexibility, and tear strength are functions of the woven fabric substrate, whereas the physical and chemical resistive properties are primarily a function of the coating material.

(3) Fabric weaving techniques as well as the inherent properties of the yarn determine the mechanical characteristics of the fabric.

(4) The lamination method of coating fabrics is not as desirable for containment boom use as the knife edge, dip or calendering methods.

(5) A coating material that does not require plasticizers generally will retain its properties longer than one that does.

(6) Polyester is the most promising substrate material, followed by nylon. Chlorosulfonated polyethylene, polyurethane with a polyether base, chlorinated polyethylene, and poly(vinyl chloride) formulated with ultraviolet inhibitors are the most promising coating materials.

(7) The great number of variations in material properties afforded by changes in coating formulations, weaving techniques, and processing methods makes it impossible to identify one substrate and coating combination as the best for use in containment boom.

(8) Standard test procedures do not exist for all of the defined material requirements; and even for properties where adequate test methods exist, sufficient data are not available on candidate materials to permit a quantitative evaluation using the weighted requirements. Where test

data are available, comparison is hampered by variations in procedures and conditions under which the data were obtained.

Based on these conclusions it is recommended that:

(1) Standard tests be developed for those containment boom material requirements for which none exist.

(2) A test program be initiated to collect the necessary data needed to perform a quantitative evaluation and comparison of candidate materials in terms of the defined requirements.

(3) Minimum acceptable values for all material requirements be established and included in boom specifications.

(4) The procurement specifications for containment booms identify material requirements and require that data substantiating the capability of the material to meet the requirements, obtained through performance of the standard tests, be provided by prospective boom suppliers.

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INTRODUCTION

Oil spill booms are continuous barriers placed in the water and extending above and below the surface to control the spread of oil or other hazardous materials that have been spilled. The booms actually serve two purposes: first, containment of the spill to limit damage to the environment, both economic and aesthetic; and second, confinement of the spill to a relatively small area to allow thickening of the oil and facilitating the recovery operation.

Although in some cases a boom is pre-positioned to guard against potential spills, generally it is used in emergency situations, after an accidental spill has occurred [1]. Therefore, the boom must be reliable. A major factor in determining reliability of a boom is the material from which it is constructed. The material must be able to withstand the adverse environmental conditions to which it will normally be subjected during its operational life without being degraded chemically or physically.

A large number of booms are available commercially, and many different types of material are used in construction. Some of these materials have performed extremely well while others have failed, resulting in additional problems and the hampering of the pollution abatement efforts. It is necessary then to identify the materials that can fulfill all the requirements for an oil spill boom. Recognizing the importance of boom material, the Naval Facilities Engineering Command (NAVFAC) has funded the Civil Engineering Laboratory (CEL) to investigate suitable materials. This project is part of a larger program assigned to CEL to develop systems for the total cleanup of Navy oil spills: Harbor Oil-Spill Removal/Recovery Systems.

This investigation was to define requirements for containment boom material, to identify current and potential boom materials, and to evaluate these materials in terms of the requirements. Results of this study will provide guidance in development of specifications and procurement of oil spill containment booms.

The study was designed to investigate the technical acceptability of materials based on published test data and other technical information. No actual testing of candidate materials was conducted at CEL. Emphasis was placed on investigating synthetic materials composed of a woven substrate or scrim impregnated with a plastic coating or laminated with a plastic surface. Plywood and metal were not considered because of the bulkiness and weight generally associated with booms constructed with these materials and because of problems with flexibility, storage, and handling. This study was also limited to boom materials for use on in-harbor oil spills where a lightweight, easy-to-handle boom is of primary importance.

In addition, although cost is of importance, an economic evaluation of materials was not included for two reasons: first, the cost of most synthetic material is variable, and second, total boom cost is heavily dependent on individual boom design and fabrication techniques as well as material costs. Therefore, a material must not be accepted or rejected based on purchase price alone, without considering total procurement costs for a particular boom design and expected useful life. This study was not based on a particular boom design; therefore, the scope has been limited to the technical suitability of the materials.

MATERIAL REQUIREMENTS

General Description of Booms

Oil spill booms come in a variety of designs, shapes, and sizes; typical is the floating boom shown in Figure 1. It consists of three basic components: a vertical fence, a flotation member, and a longitudinal strength member.

The vertical fence, which extends both above and below the waterline, may be made of either a rigid or flexible material and usually incorporates ballast along the bottom to keep it properly oriented.

The flotation member may be an integral part of the fence or attached externally as shown in Figure 1. If integral, the buoyancy may be provided by gas-filled chambers or by plastic foam beads or logs. If external, logs or blocks of rigid or semirigid plastic foam are generally used.

The longitudinal strength member may be a cable, rope, or chain running the length of the boom or may be a webbing incorporated in the fence fabric. In some boom configurations the load-carrying capacity is developed by the fence material itself.

Requirements

The wide variation in boom configurations makes it difficult to identify one material as ''best''; a good material for one boom design may not be suitable for another. However, this study is not concerned with boom design per se; every attempt has been made, therefore, to reduce the impact of boom design on the selection of boom material. The material requirements that follow are based on boom performance characteristics and have been established by consulting current specifications for booms [2] and through consultation with personnel engaged in the design, manufacture, and procurement of booms as well as with those having direct operational experience. The requirements include structural, physical, and chemical resistive properties of the materials. Where possible, applicable standard test procedures have been identified.

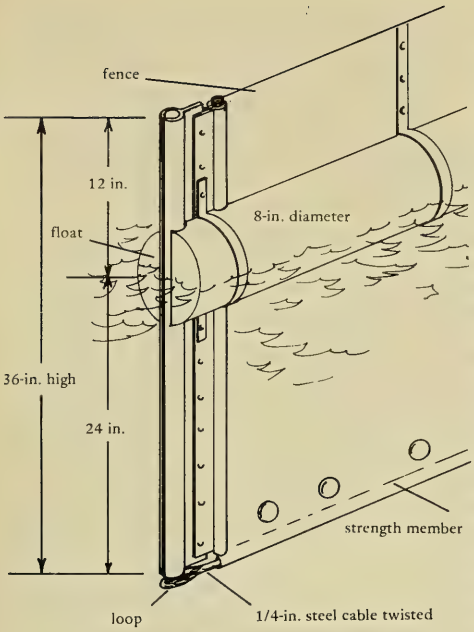

Figure 1. Typical boom.

Break Strength. The material must have sufficient tensile strength to withstand a load of at least 450 pounds per inch of width in both the longitudinal and transverse directions. Containment booms are subjected to a variety of structural loads during operation. These loads come from wind and wave action as well as from water currents when a boom is anchored or held in position by boats. Additionally, during emergency situations, booms are often towed through the water to the spill site at speeds up to 10 knots. The loads applied during these tows is dependent on the hydrodynamic characteristics of the particular boom design. The breaking strength requirement pertains primarily to the fence material rather than to the flotation material. However, in certain designs, the same strength may also be required in the flotation. Also, in some designs, the fence fabric serves as the primary strength member, in which case the fence material must meet the static line pull requirements for the complete boom specified in Military Specification MIL-B-28617B (YD). To determine the breaking strength and to allow comparisons between material, the materials should be tested in accordance with Federal Test Method Standard (FTMS) 191 Method 5102 [3].

Tear Propagation Resistance. The material must not tear easily after being cut, snagged, or punctured. The fabric should rope up* to limit the propagation of a tear once it has started. The boom material must offer sufficient resistance to the propagation of tears to prevent the boom from failing completely by being severed when subjected to the high tensile load encountered under operational conditions.

Booms can incur rips or cuts during deployment and retrieval operations as the boom is dragged along the ground or pulled over the side of piers and docks. They can also become snagged on pilings or damaged by floating debris while in use. On-shore handling of booms incidental to actual spill control operation can also result in tears and cuts to the

* Slippage of the yarns so they bunch together rather than breaking as the tear progresses.

fabric. Tears in the material offer avenues through which spilled oil can escape, thereby reducing the overall effectiveness of the boom.

The resistance to tear propagation applies primarily to the fence material rather than to the flotation material unless the flotation actually serves as a portion of the vertical barrier. The resistance to the propagation can be measured by testing the material in accordance with FTMS 191 Method 5134. For acceptibility, a material must exhibit a tear strength in both the warp and fill directions of 200 pounds as specified in MIL-B-28617B (YD).

Adhesion of Coating. The coating on the material must not separate from the fabric when the material is under stress. Such separation weakens the material, exposes the fibers to the environment, and shortens the life of the boom. MIL-B-28617B (YD) invokes FTMS 191 Method 5970 for determining the adhesion of the coating. However, an acceptable capacity for adhesion is not specified. Instead, the specification requires an 80% retention in adhesive capacity after immersion in fresh water for 16 days at 120°F. Stating the requirement in this manner avoids conflict with the requirement for tear resistance. Generally, the adhesion of the coating varies inversely with the tear resistance of the material. The greater the adhesive strength, the less tendency there is for the fabric fibers to rope up as the material is torn. The coated material will therefore tear much more easily then the uncoated fabric.

Puncture Resistance. Punctures can occur in booms during all phases of operation and handling. The ability of a fabric to resist punctures from sharp objects is especially important for booms using inflatable flotation members or those using beads or chips of flotation material enclosed in a chamber. If these members are punctured, the flotation medium can escape and that portion of the boom may sink, thus permitting spilled oil to pass over. Punctures also weaken the material and breaking or tearing under operational tensile loads can occur.

A standard test method for measuring the puncture resistance of flexible barrier materials is FTMS 101B Method 2065. This method specifies that an increasing load be applied to the material using a moving probe to determine the force required to puncture. Another method that has been used to measure the puncture resistance of tarpaulin fabrics employs a puncture comparator machine [4]. With this device a needle-pointed projectile is dropped a specified distance down a shaft where it pierces a tightly held section of the test material. The distance the projectile penetrates the material is an indication of the relative puncture resistance.

Abrasion Resistance. The material must be capable of withstanding mechanical action that tends to remove material from its surface, such as rubbing, scraping, or erosion. Abrasion damage to the boom weakens the material and is incurred in much the same manner as tears and punctures. Not only is the structural strength lowered but resistance to chemicals and water absorption are lowered, thereby shortening a boom's useful life and increasing maintenance requirements.

Abrasion resistance is important in both the fence material and the float material if the latter is exposed. If the flotation is encased, the abrasion resistance applies to the casing material.

The abrasion resistance of material can be measured using the FTMS 191 Method 5304 which determines the change in breaking strength of the material after subjecting it to unidirectional rubbing action under controlled conditions of pressure, tension, and abrasion. A material, after being tested by this method and in accordance with MIL-B-28617B (YD), must have a breaking strength of at least 270 pounds per inch of width to be acceptable as boom material.

Flexibility. The material must have sufficient flexibility to permit it to conform to the waves without loss of freeboard or draft. Under certain wave conditions the rigidity of the boom may cause it to bridge; that is, a portion of the boom will be suspended across the trough of the waves from crest to crest so that the bottom portion of the boom is actually out of the water. This complete loss of barrier draft represents failure of the boom because eventually all oil would escape. The boom must therefore be able to articulate with the waves so that the fence maintains sufficient draft to prevent the oil loss.

Depending on the design of the boom, a certain amount of rigidity in the material is required (for instance, for a fence-type boom to maintain its freeboard or draft against wind and currents as well as waves). Stiffeners are often used with flexible materials to increase rigidity in the vertical direction. Other methods for maintaining draft with flexible materials include the use of bottom and top tensioning cable and ballast weights attached to the bottom portion of the boom. Flexible joints are often used in boom designs utilizing rigid materials.

Flexibility is also required for boom storage and handling. The material must be capable of being bent or folded in a relatively small radius for prolonged periods without cracking, breaking, or taking a permanent set.

Flotation material as well as fence material must be flexible in many boom designs, especially those utilizing continuous rod or log-type foam floats.

Although standard test methods exist for measuring the directional flex-stiffness of cloth, such as FTMS 191 Methods 5200 and 5204, the flexibility of the material is not one of the parameters currently identified in MIL-B-26617B (YD). The flexibility of the entire boom is visually observed, however, under operational conditions to verify the boom's ability to conform to the water surface. Because of the impact the boom design has on the degree of flexibility required in a material, it is not possible to establish flexibility criteria as was done with breaking strength and other parameters. So, although flexibility is a definite consideration, it is not advisable to quantify it unless a specific boom design is being addressed.

Elongation and Permanent Set. The material must not stretch excessively when subjected to operational loads, and should return to pre-load lengths after removal of the load. It should be dimensionally stable under varying conditions of load, moisture, and temperature. This stability is important to insure that the boom retains its shape and features while under operational conditions in seawater.

The elongation capacity of a material can be expressed in terms of percent of original length when stretched to breaking, as determined from FTMS 191 Method 5102, in terms of the stress-strain curve for the material or in terms of its 100% modulus which is the stress required to elongate the material 100% of its original length.

A relatively low total elongation of a fabric, characterized by a steep stress-strain curve and high 100% modulus, and recovery from elongation are desirable for containment boom material to prevent the boom from losing its shape when subjected to uneven load distribution along the height of its cross section as is normally encountered with a floating barrier subjected to wind, wave, and current forces. The below-water portion of the curtain material subjected to the greater current loads can cause boom failure through loss of draft as the load relieves itself through fabric stretching.

Required values for the elongation properties of a boom material have not been established. The requirements must, however, be based on boom design.

Low Density. In emergency spill situations the boom must be deployed as quickly and with as few personnel as possible; therefore, the lighter the boom the easier it is to deploy and retrieve. A lightweight material, however, must also have sufficient strength, so lower density material may need to be thicker or bulkier to develop the required strength. The strength-to-weight ratio of a material offers a means of comparing materials for density.

Nonporous. The material must be impervious to petroleum or its derivatives. No standard test exists for measuring the porosity of the material with respect to oil. However, FTMS 191 Method 5512 measures the resistance of coated cloth to the passage of water under high pressure. This same test can be used for measuring the porosity of the material with respect to petroleum products by substituting the specific petroleum product for the water in the test. This test actually measures the pressure at which the liquid first appears on the other side of the material.

High Temperature Resistance. In exposure to high temperatures, there must be no appreciable change in the flexibility of the material, and it must not become tacky or block. A boom may be subjected to high temperatures during storage for prolonged periods or during hot water cleaning after use. Temperatures can be expected to be as high as 180°F. FTMS No. 191 Methods 5870 and 5872 are standard methods for measuring the effects of high temperature on material flexure and block-

ing. Method 5870 specifies measurement of changes in the stiffness of the material from that exhibited at room temperature and specifies that results be expressed as a percentage. Method 5872 defines blocking and specifies that test results be expressed in terms of no blocking, slight blocking, and blocking.

Low Temperature Resistance. The material must not stiffen, become brittle, or crack when subjected to cold temperatures. This is important for booms that are kept in storage and used in colder climates. Also, the boom may be subjected to cold temperatures during transport to the user activity. Cracks in the coating of the material can reduce its resistance to the environment and petroleum products, increase its porosity, and lower its breaking strength, thus lowering its effectiveness and shortening its useful life. FTMS No. 191 Method 5874 is cited in MIL-B-28617B (YD) for testing the low temperature resistance of boom material. This test determines the degradation of the material as a result of exposure to temperatures of $-20^{o}F$ by measuring the percent change in hydrostatic resistance of the material. A change of 5% or less is acceptable.

Weather and Water Resistance. There must be no appreciable change in the structural, physical, or chemical resistance properties of the material after prolonged exposure to ultraviolet light, ozone, or fresh or salt water. This property applies to both flotation and fence material if it would normally be exposed to the environment. An accelerated weathering test is called out in MIL-B-29617B (YD) using FTMS 191 Method 5804. This method exposes the material to carbon arc light and a water spray for a specified period of time. The test as written does not evaluate the effects of immersion in seawater or ozone on the material.

Resistance to Petroleum Products. To be acceptable the material must not be degraded physically or mechanically because of contact with oil* products. This requirement also applies to the flotation medium if it will normally come in contact with spilled oil under operational conditions.

No standard tests exist for measuring the resistance of materials to various petroleum products. However, standard methods could be developed around ASTM Method D543, Resistance of Plastics to Chemical Reagents. This method calls for the immersion of a material sample in the reagent solution of a specified concentration, at a given temperature, for a specific period of time, and under controlled atmospheric conditions. While the specific test conditions can be changed to accommodate the various petroleum products, the same conditions must be used for a given petroleum product to permit comparison of the relative resistance of materials being considered. Following immersion, the materials can be tested for changes in physical or mechanical properties by comparing test results with those obtained with untreated samples of the material.

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* Crude through refined and treated oil.

Colorability and Colorfastness. The material must be capable of being produced in international orange or high visibility yellow and of resisting discoloration and fading when exposed to the environment or oil products. Visibility is important to prevent damage to the boom from passing ships and also to avoid entanglement of the boom with the ship's propeller. This is especially important for booms containing wire cables or chains.

The colorfastness of materials can be observed during the tests of the material for resistance to weathering and the resistance to petroleum products.

Flame Retardancy. The material should not propagate fire when exposed to open flame and should be self-extinguishing when the source of flame is removed. This requirement does not greatly affect the effectiveness of the boom but from a safety point of view is more important during storage than during operational conditions; a fire during an oil spill is an unlikely occurrence unless a highly volatile substance is spilled.

The flame retardancy of material can be measured using FTMS 191 Method 5900 or 5903.

Resistance to Water Absorption. The material must not absorb moisture when immersed in water for prolonged periods or when subjected to high relative humidity conditions. Resistance to the absorption of water is critical in both the curtain and flotation material. An increase in the weight of the boom makes it more difficult to handle on land and in the water. The extra weight will also reduce the boom's reserve buoyancy and affect its ability to respond to the waves. Also, absorption can cause a more rapid degradation of the material. FTMS 191 Method 5500 or 5502 can be used to compare the absorption characteristics of materials.

Resistance to Marine Growth, Fungus, and Mildew. The material should resist the growth of marine organisms when immersed in saltwater for prolonged periods and should resist fungus attack and mildew growth following exposure to the marine environment or during storage for prolonged periods.

Resistance to marine growth is especially important for permanent booms that will remain in the water for weeks or months at a time. Such resistance will reduce maintenance requirements. Resistance to marine growth is dependent upon antifouling coatings applied to the material, but these coatings pose a pollution problem themselves as they leach into the marine environment.

No standard test has been established to measure resistance to marine growth. FTMS 191 Method 576D presents a standard method for measuring the mildew resistance of material.

Repairability. The material must be capable of having tears, breaks, and punctures repaired in the field in a relatively short period of time and without excessive tools or manpower. Ideally, repairs to a

boom should be made when they occur to avoid further damage and to maintain the integrity and effectiveness of the boom. Since damage to the boom often occurs when the boom is in the water or being deployed, the capability to repair the boom in the water is desirable. This capability can reduce the time and expense associated with pulling the boom onto dry land to effect repairs or shipping it back to the shop or manufacturer. The repairability of material can be measured in terms of the type of adhesive, curing time, heat, and pressure required to bond the material and also the strength developed by the bond.

Cleanability. The material must be easily cleaned of petroleum products, marine growth, or contaminants that might accumulate on the material under operational conditions. Commercially available industrial detergents and hot water must be used for cleaning without abrasive or other adverse effects on the mechanical or physical properties of the material. Cleaning is important for safe storage, to facilitate handling, and to prolong the life of the boom.

No standard tests are defined for measuring the cleanability of materials but judgment can be based on observation of actual attempts to clean the material. Also, the chemical resistance of the material to the cleaning agents in the recommended concentrations could be used as a measure of cleanability.

Evaluation of the Materials

The recommended minimum values and standard procedures for evaluating a material in terms of the preceding requirements are summarized in Table 1.

To evaluate materials in terms of these requirements each requirement must be weighted relative to the others. Since the importance of a requirement is a matter of judgment, individuals having expertise in the area of oil spill containment were consulted to obtain their evaluation of the relative weight of each requirement. As a result of this inquiry, the requirements as originally proposed were modified: some were combined and others added or eliminated to obtain the revised requirements.

The last column in Table 1 lists the weighting value assigned to each of the fence material requirements as a result of the inquiry. The values total 100% and were established by averaging the individual responses, modified where necessary to reflect the revisions.

The requirement of resistance to petroleum products and non-porosity were determined to be Go-No Go type requirements for fence material. If a material does not meet either of these requirements it is unacceptable for use as oil containment boom. These two requirements are therefore multiplicative, rather than additive factors and have not been assigned a weighted value.

Material not meeting these two requirements may be acceptable as flotation material if the design of the boom is such that the flotation material does not come into direct contact with the oil and does not actually serve a containment function. Under these circumstances these requirements can be considered additive along with the other requirements.

Table 1. Material Requirements for Oil Spill Containment Booms

Property	Recommended Minimum Value	Recommended Standard Test	Weighted Value (%)
Break strength	450 lb/in. of width	FTMS No. 191 Method 5102	8.8
Tear resistance	200 lb (warp and fill)	FTMS No. 191 Method 5134	8.8
Adhesion of coating	80% retention after immersion for 16 days at 120°F	FTMS No. 191 Method 5970	5.2
Puncture resistance	Not established	FTMS No. 101B Method 2065	8.6
Abrasion resistance	Breaking strength after abrasion for 2,000 Hz with 80-grit garnet 270 lb/in. width	FTMS No. 191 Method 5304	8.0
Flexibility	Not established	FTMS No. 191 Method 5200 or 5204	8.0
Elongation	Not established	FTMS No. 191 Method 5102	4.2
Low density	Weight in lb/sq yd between 1 and 2 lb	Direct weighing of the material	4.3
Nonporosity	Not established	FTMS 191 Method 5512 modified to use oil instead of water	—*
High temperature resistance	180°F — No blocking	FTMS 191 Method 5870 or 5872	4.2
Low temperature	-20°F <5% change in hydrostatic	FTMS 191 Method 5874	4.5
Weather resistance	Not established	FTMS 191 Method 5804 modified to include sea-water spray	5.4
Resistance to petroleum product	Not established	ASTM D543 modified to use specific petroleum products	*
Colorability	Observation	Observed during tests of weatherability and resistance to petroleum products	2.6
Flame resistance	Not established	FTMS 191 Method 5900 or 5903	2.7
Resistance to water absorption	Not established	FTMS 191 Method 5500 or 5502	5.8
Resistance to mildew and marine growth	Not established	Mildew – FTMS 191 Method 5760 marine growth — not established	4.7
Repairability	Not established	Measure time required to make repair and strength of bond	7.2
Cleanability	Not established	Not established	7.0
TOTAL			100.0

* Go-No Go Properties; material must meet these requirements to be considered for use as containment boom material.

Assignment of weighting values to the requirements for flotation material has not been included in this report. The large variations in the manner in which the flotation is incorporated into the design of the booms precludes the establishment of weight values for flotation material in general. What may be an essential flotation requirement for one boom may be completely irrelevant in another design.

COATED FABRICS

This study is directed primarily at synthetic plastic material rather than wood or metal. These synthetic materials are generally composed of two parts: the woven fabric substrate or scrim and the elastomer or resin coating. The capability of a particular material to meet the requirements defined depends upon the type of weave, amount of yarn and method of manufacturing the fabric, and the thickness and method of applying the coating.

Fabrics

The substrate yarns used in coated fabrics must be interlaced or woven into cloth. It is the techniques used in weaving the yarns that provide many of the mechanical and structural features of the cloth.

A woven cloth is composed of two sets of yarns: the warp yarns that run longitudinally in the cloth and the filling yarns that cross the warp yarns at a 90-degree angle and run the short direction from selvage to selvage [5]. Selvage is the edge of the cloth in the direction parallel to the warp yarns. Generally, in weaving cloth the warp yarns are held under more tension than the filling yarns, resulting in differences in the strength and elongation characteristics of the fabric in the warp and filling directions.

In producing fabrics there are basically three types of weaves that are used, the plain weave, the flat weave, and the twill weave. In the plain weave, each warp yarn passes over one filling yarn and under the next. Every other warp yarn is woven the same as is every other filling yarn. The result is a cloth that is even sided; that is, the face is the same as the back. Plain woven fabrics exhibit the maximum number of interlacings, or points at which one yarn passes over another. The yarns in a plain weave may be either single or plied. Plied yarns are those for which two or more single yarns are twisted together to form one yarn.

The flat weave fabrics are characterized by a pair of warp yarns woven side by side as one, flat. The warp yarns are not plied; the filling yarns may be either single or plied. Each filling yarn passes over two warp yarns then under two warp yarns. The flat weave has fewer interlacings than the plain weave. Cloths woven in this manner, with side-by-side yarns provide greater tearing resistance because slippage occurs before rupture of the yarns (roping up).

In the twill weave a warp yarn passes over two or more filling yarns. There may be a warp twill or filling twill and a plain twill or broken twill. The warp twill has more warp yarns per inch than filling yarns; a filling twill has more filling yarns per inch. In a broken twill the interlacing does not fall in a close regular pattern as they do in the plain twill. For the most part, the yarn in twill weaves may be either single or plied.

These are the basic weaves but the variations possible are almost limitless. One common variation is the oxford or basket weave which is a modified plain weave. In this weave, combinations of two or more yarns are woven side by side in both the warp and filling directions. The yarns may be single, plied, or a combination of both.

The strength of a fabric is dependent upon the technique used in weaving the cloth and the size of the yarn. The fineness or size of a yarn is often expressed in denier. The denier of a yarn is the weight in grams of 9,000 meters of the yarn: the coarser the yarn, the higher the denier. Use of heavier yarns or plied yarns instead of single yarns can increase the strength and the stiffness of a fabric. For example, a fabric may be made more stiff in the filling direction than the warp direction by using four-ply yarns for the filling and two-ply yarns for the warp. Thus, it is possible to construct a fabric with just about any structural or mechanical characteristic desired. The actual kind of substrate used does not by itself dictate the properties of the finished fabric.

Coatings

The coating that is applied to the woven fabric substrate imparts many of the physical and chemical resistive properties to the finished material.

Four common methods are used for applying the coatings to fabrics: spread or knife coating, dip, calendering, and laminating [6].

In knife or spread coating the fabric is pulled underneath a knife edge which meters the quantity and thickness of coating applied. The coated fabric is then passed through a drying or curing oven. This method is suitable for applying thin coatings to one side of the fabric. Thicker coatings and coating on both sides of the fabric can be obtained by passing the fabric through the equipment a number of times.

In the dip method the fabric is immersed in a bath of the coating compound before passing between a set of metering knives and then into the drying or curing oven. This method has the advantage of coating both sides of the fabric at one time, and the fibers of the fabric become impregnated with the coating. This process may be repeated more than once to obtain the required coating thickness.

The calendering process involves passing the fabric between two rollers where the fluid coating is forced onto the fabric. The equipment can be designed to coat one or both sides of the fabric. The method is good for applying thick coatings.

During the lamination process, thermoplastic films of the coating material are pressed onto the bare fabric as the film and fabric pass through a set of rollers. The films can be applied to either or both sides of the fabric in any thickness required. Adhesion of coating in the lamination process depends upon the bond formed by the contact of the films through the openings in the base fabric. To insure a strong bond an open weave cloth is necessary. In general, laminated coatings do not result in the yarns of the fabric being as well encapsulated or chemically tied to the coating. Consequently, the yarns often pick up moisture, oil, and bacteria which tend to degrade and discolor the material. In cold climates the freezing and thawing of the moisture trapped in the laminated material can cause the coating to crack and separate from the substrate.

These are the basic coating techniques in common usage. All methods permit the construction of coated fabrics in a variety of thicknesses. The thickness of the coating can have both good and bad effects. Thicker coatings generally make for heavier, less flexible material, but also result in better protection for the substrate from the elements and increased service life. Like fabric weaves, many variations and combinations of the above methods are being used. Each manufacturer of coated fabrics has his own processing technique, making available a wide range of charteristics, quality, and cost.

SUBSTRATES AND COATINGS

There are a great many different materials that can be spun or drawn into yarn to serve as the basic fabric and just as many different materials that can be used as coatings. The purpose of this section is to discuss the relevant characteristics of many of these materials and identify the more promising one. References 6 through 24 describe these materials and their characteristics.

Substrate Materials

Substrate materials can be either manmade or natural fibers such as cotton and wool. A list of fibers is shown in Table 2 with some key physical and structural properties. Based on the information in Table 2, the following were selected as having the most suitable properties for use as substrate material in coated fabrics for containment booms; (1) acrylic (Orlon), (2) modacrylic, (3) nylon, (4) polyethylene (low and high density), (5) polypropylene, (6) polyester, and (7) glass. Acetate, nytrile, saran, fluorocarbon, and wood fibers were rejected because of their low strength-to-weight ratio; acrylic, modacrylic and polyethylene were considered marginally acceptable. The strength-to-weight ratio was calculated by dividing the tensile strength of the fibers in pounds per square inch obtained from published literature [6,7,8,13,18,19] by the specific gravity of the fibers. Tensile strength was used rather than breaking strength because the substrate was being evaluated and not a complete coated fabric.

Table 2. Substrate Materials

Fiber	Specific Gravity	Tensile Strength (1,000 psi)	Strength-To-Weight Ratio	Ultimate Elongation (%)	Average Stiffness (Flexibility) (grams per denier)	High Temperature Resistance	Weather Resistance	Resistance to Salt Water	Resistance to Organic Solvents	Water Absorption (%)	Mildew Resistance
Acetate	1.32	22-28	17-21	23-24	5.5	good	good	good	good	6	high
Acrylic (Orlon)	1.14-1.19	30-40	25-35	20-28	10	good	good	good	good	1.5	not attacked
Modacrylic	1.30-1.36	42-50	31-38	39	7.7	good	–	–	good	1.4	NA
Nylon	1.14	67-86	59	24-40	18	good	good	good	good	4-5	NA
Nitrile	1.2	30	25	30	7	good	–	–	good	2-3	NA
Polyethylene (low density)	0.92	11-35	12-38	20-80	2-12	fair	–	–	good	none	NA
Polyethylene (high density)	0.95	50-90	53	10-20	20-50	good	–	–	good	none	NA
Polypro-pylene	0.90	50-90	55	15-25	20-60	good	poor	–	good	none	NA
Polyester (Dacron, regular)	1.38	77-88	55	19-25	21	good	good	good	good	0.4-0.8	NA
Polyester (Dacron, high tena-city)	1.38	111-138	80	10-14	56-63	good	good	good	good	0.4-0.8	NA
Rayon (Forison-36)	1.5	155	103	6.2	135	good	fair	–	good	3	attacked
Saran	1.7	15-45	9-26	15-25	7-10	fair	good	–	good	none	NA
Glass (E fiberglass)	2.54	200-220	78	3-4	322	good	good	good	good	none	NA
Fluorocarbon (Teflon)	2.3	47	20	13	12	good	good	good	good	none	good
Cotton	1.54	44-109	28-71	3-7	57-60	good	good	good	good	7	poor
Wool	1.32	20-29	15-22	25-35	39	fair	poor	–	good	16	good

Rayon and cotton were considered unsuitable because of the poor mildew resistance and high percentage of water absorption of these fibers [7].

Weatherability was another factor considered in the selection of substrate material. In a direct-exposure weatherability test conducted by Dupont [7], acrylic (Orlon) was found to be relatively unaffected by both long and short wavelengths of ultraviolet light and nylon and polyester (Dacron) have very good light and weather-resistance properties.

Acrylic fibers, by definition, contain at least 85% by weight of acrylonitrile units. Acrylic fibers vary in their physical and chemical properties, depending on their intended application. They are produced in high tensile strength yarns that are in the same range as cotton. They have good resistance to deformation both dry and wet and retain their strength after prolonged exposure to high temperatures. Acrylic fibers are unaffected by detergents, oils, or biological attack and have excellent resistance to sunlight. However, under high temperature and stress conditions, acrylics do not perform well and have not found much industrial application [8,10,11,12].

Nylon fibers, in addition to their high tensile strength, are extremely tough and resilient, retain their properties at elevated temperatures, and generally have good resistance to organic solvents and chemicals [14,15,16]. The water absorption rate of nylon is considerably higher than polyester or acrylic. It is also not as dimensionally stable as polyester.

Modacrylic fibers are copolymer fiber containing less than 85% acryonitrile. The fibers are strong and tough and feel similar to wool. The fibers are not as good as nylon or polyester in abrasion resistance [7,17]. The fibers retain most of their tensile properties over a broad temperature range and have excellent chemical resistance and resistance to insects, fungi, and micro-organisms. One problem with the modacrylic fibers is the softening range. However, this would be more of a production rather than an operational problem since the softening temperature is above the temperature that would be expected during use. Because of this softening around temperatures of 250^{o}F to 300^{o}F, modacrylics are not as widely used as other fibers and, therefore, may not be as readily available.

Polyethylene and polypropylene are members of the generic class of fiber known as polyolefins and by definition have at least 85% by weight of ethylene, propylene, or other olefin [17]. Polypropylene fibers have a lower specific gravity than any other commercial fiber, and highly oriented fibers have high tensile strength. The major drawback to polypropylene is its rapid degradation in weather [4].

Polyethylene is more suitable for plastic film rather than fiber applications. The fibers are not strong and can be elongated excessively. Polyethylene also has an extremely low melting point and poor weatherability; the fibers shrink when exposed to elevated temperatures in the presence of water. Polyethylene is inert to most chemicals but is not easy to coat unless chemically modified.

Polyester fibers by definition are composed of at least 85% by weight of an ester of a dihydric alcohol and terephthalic acid [17]. Polyester fibers are more dimensionally stable than nylon or acrylic (Orlon), have a high tensile strength and high elastic recoveries from small deformations [8]. The elastic modulus is much higher than that for corresponding nylons. Another feature of the polyester fibers is the retention of mechanical properties when wet. They also absorb little water and have excellent resistance to most chemicals and organic solvents as well as good weathering characteristics. Polyester fiber is much more ultraviolet resistant than nylon.

Glass fibers exhibit nearly all of the properties desirable in a fiber suitable for containment boom with the exception of stiffness. The fibers are much more rigid than any of the other manmade or natural fibers. Glass fibers when used in a situation requiring large flexures tend to cut themselves as they rub against each other. For this reason these fibers are generally used in rigid plastic situations rather than in coated fabrics that will be subjected to continuous flexing.

As a result of the examination and comparison of the properties of the manmade and natural fibers, nylon and polyester fibers appear to be the most appropriate for use as a substrate for coated material for containment boom. The acrylic and modacrylic fibers also exhibit all the necessary characteristics but have much lower strength-to-weight ratios than either nylon or polyester. Polyester has an advantage over nylon because of the greater dimensional stability and better water absorption characteristics.

Coating Materials

Nearly all coating materials used in any quantity today are synthetic. Coatings can be generally categorized as rubber or plastic. Plastic materials by definition contain at least one polymeric substance of large molecular weight that is shaped by flow during processing but is a solid in its finished state [20]. Rubbers are materials capable of recovering from large deformations quickly and forcibly and have been modified such that they are essentially insoluble in boiling solvents. These definitions are not mutually exclusive. Materials having properties of both plastic and rubber are generally classified as rubber.

Another term used in a broader sense is elastomer. Elastomers are substances capable of being stretched to twice their original length at standard conditions and, once the stretching force is removed, return almost immediately to their original length. Thus, many plastic and rubber materials can be considered elastomers.

The number of different plastics and rubber materials being used commercially in coated fabrics is extremely large and to discuss the attributes of each of them would be a time consuming task and would not add significantly to this report. As stated in MATERIAL REQUIREMENTS, for a coating to be suitable for use in a containment boom, it must be resistant to degradation from oil or other petroleum products it may

come in contact with under operational conditions. Resistance to oil is generally an inherent property of the material that cannot be changed by the addition of plastic or other modifiers. This requirement was used to initially screen the variety of materials available [21,22]. Further screening was accomplished by considering general weathering and flexural properties to obtain the list of candidate coating materials contained in Table 3 [17]. The coatings impart much of the physical and chemical resistive properties to the complete material with the exception of strength which is usually determined by the woven fabric substrate. Table 3 also contains information on the properties of these coatings as published by the manufacturers [22].

Nearly all of the coatings indicated in Table 3 would be suitable for use on containment boom. Many of them offer exceptionally good characteristics. For instance, the Viton and Teflon have excellent resistance to most oils, fuels, and many aliphatic and aromatic hydrocarbons, are virtually unaffected by weather and high temperatures, and have outstanding abrasion resistance [17,21,22]. Perhaps the main technical drawback to Viton or Teflon is their high specific gravity which would make a containment boom heavy and difficult to handle. Teflon also presents some problems in processing because of its low coefficient of friction and its nonadhesive character. On the nontechnical side, the specific gravity coupled with the high price of the elastomers makes its use almost prohibitive.

The polyester elastomer Hytrel [22] also exhibits nearly all the properties required in a coating material for containment booms. It's use would necessarily be restricted to substrate other than polyester although use without reinforcing substrate is possible because of the high tensile strength of this material.

Polyurethanes also exhibit extremely high tensile strength and can be used without a reinforcing substrate although they can be combined with polyester or nylon fabrics to obtain a coated fabric possessing nearly all the requirements for containment booms [22,23]. Polyurethanes generally have either a polyester or polyether base. Polyester-based urethanes do not perform well in the presence of moisture and are not recommended [11]. On the other hand, the polyether-based urethanes exhibit good resistance to moisture. This resistance improves as the coating thickness increases; with thicker material the flexibility is reduced. The stiffer material may impair the wave conformance capability of the containment boom.

Poly(vinyl chloride) (PVC) can be made to have all the qualities required in a containment boom material through the addition of plasticizers to improve its flexibility and resistance to ultraviolet light and oxidation [17]. A problem with materials that use plasticizers is that the plasticized plastics are subject to swelling after prolonged exposure to oils resulting in shortened operational life of the material.

Table 3. Coatings for Fabrics

Coatings	Specific Gravity	Tear Resistance	Abrasion Resistance	Flexibility	Adhesion	High Temperature Resistance	Low Temperature Resistance	Mildew Resistance	Resistance to Water Absorption	Flame Resistance	Colorability
Poly(vinyl chloride) (PVC)	1.2-1.5	good	good	good	good	good	good	fair-good	good	fair-good	excellent
Chloro-sulfonated polyethylene (Hypalon)	1.12-1.28	fair	excellent	excellent	good	excellent	good	good	very good	good	excellent
Chlorinated polyethylene (CPE)	1.35-1.39	fair	fair	good	excellent	good	good	good	good	NA[a]	poor
Neoprene	1.23	good	excellent	good	excellent	excellent	fair	good	good	good	poor
Polypropylene	0.90	good	good	good	NA	good	fair	good	excellent	fair	good
Nitrile rubber	1.18	fair	good	excellent	excellent	good	excellent	good	excellent	fair	poor
Polyurethane (Adiprene)	1.06	excellent	outstanding	excellent	excellent	good	excellent	good	good	fair	good
Fluorocarbon (Teflon)	1.7	NA	good	good	NA	excellent	excellent	good	excellent	good	NA
Polyester (Hytrel)	1.17-1.22	excellent	outstanding	good	good	excellent	excellent	good	very good	fair	NA
Vinylidene Fluoride and hexafluoro-propylene Co-polymer (Viton)	1.85	fair	good	good	good	excellent	outstanding	good	very good	good	NA

[a] NA = not available.

Chlorinated polyethylene exhibits all the physical and chemical resistive properties except for resistance to aromatic and chlorinated hydrocarbons. Unlike PVC, chlorinated polyethylene coatings contain no plasticizers and have excellent aging property characteristics. The properties of tear and abrasion resistance of this material are not as good as those exhibited by others in Table 3. However, tear resistances can be improved considerably when the coating is used with a fabric substrate such as nylon or polyester [24].

Chlorosulfonated polyethylene is superior to the chlorinated polyethylene in that it exhibits excellent abrasion resistance and can also be produced in a wide variety of colors. Its weak property is tear resistance but this, as with the chlorinated polyethylene, is greatly improved when the material is used with a polyester or nylon substrate [22].

Nitrile rubbers, after immersion in oils, retain their good strength and abrasion resistance. Depending on the percentage of acrylonitrile and butadiene nitrile rubbers can have a good balance of solvent resistance, high temperature resistance, and low temperature flexibility [17]. The weathering properties of nitrile rubbers are not as good as chlorosulfonated polyethylene, however.

Neoprene is a very resilient synthetic rubber that has excellent flexural strength but is not as good as chlorosulfonated polyethylene in all but tear resistance [17,22]. Although neoprene can be produced in almost any color the lighter colors tend to discolor when exposed to sunlight. No other information was available on the effects of colors on the physical properties of neoprene or the resulting degradation with exposure of colored neoprene to sunlight.

Polypropylene is very low in density and offers good balance in mechanical, physical and chemical resistive properties. Its resistance to sunlight is only fair. Reference to its use as a coating for fabrics has not been found in the literature except for reinforcement with fiberglass which makes it stronger and more rigid [17].

While the coating materials presented in Table 3 do not represent a complete list of those materials that may exhibit the desirable properties, they are fairly representative of those being used today in coated fabrics. An indefinitely large number of formulations, combinations, and modifications are possible and each one can change the properties of the material and hence its suitability for use on containment booms. This discussion has identified some of the primary properties of the basic coating materials.

MATERIAL EVALUATION

The discussion in the previous sections identified woven substrate and coating materials exhibiting the most promising characteristics for use as containment booms. To determine the types of coated fabrics currently being used in booms, a number of manufacturers were contacted and information concerning the materials and their properties obtained.

Some of these materials are presented in Table 4. It was apparent from this survey that there is much duplication of the types of material being utilized. By far the most popular material is a PVC coating over nylon. In addition to the boom manufacturers a number of suppliers of coated fabrics were contacted and consideration was also given to materials manufactured primarily for use as pond and reservoir liners. Certain of these materials are included in Table 4.

In the course of gathering information on specific boom materials it became evident that a comparison of materials on a property by property basis and a realistic evaluation of them in terms of the weighted requirements developed in Section 2 would not be possible. Although for most of the requirements listed in Section 2, standard tests exist, there are a few for which no standard tests are defined, thus preventing an evaluation of materials in terms of these requirements. Even for those requirements for which standard tests exist, a comparison of material on this basis is restricted by the fact that many materials have not been subjected to the tests, or if they have, the procedures or conditions under which the tests were run were not standard, but varied between material types and manufacturer. Consequently, much of the quantitative data needed to complete an evaluation are missing. The only positive way of comparing candidate boom material in terms of the weighted requirements is to develop the missing data through actual testing. Therefore, no numerical rating of boom materials has been attempted. Instead, listed in Table 4 are the measured values for the important properties of the individual materials as determined by the manufacturer or supplier and only a qualitative comparison is presented [23-30].

All of the requirements for containment boom materials defined in Section 2 are represented in Table 4 with the exception of flexibility, repairability, and cleanability.

As indicated in Section 2, the amount of flexibility required in a material is dependent on boom design and no quantitative values for acceptable flexibility have been established. While all the materials listed in Table 4 can be described as flexible, no test data were provided in the literature available from the manufacturers or suppliers to permit comparison. This property was therefore excluded from Table 4.

The cleanability of a material must be based on its ability to resist degradation from hot water, industrial strength detergents, and solvents that dissolve crude and refined oil products. Polyurethane and nitrile rubber can be severely affected by exposure to steam or hot water at 212^{o}F, although they are unaffected by water at lower temperatures. Although no test data were available, it is doubtful that any of the coated fabrics would be significantly affected by exposure to most detergents. When booms are contaminated with heavy deposits of weathered oil they are sometimes washed with kerosene prior to cleaning with a detergent. All the materials listed in Table 4 are degraded to some extent by exposure to kerosene.

Table 4. Candidate Materials for Oil Spill Containment

Materials	Weight (oz/yd^2)	Thickness (inch)	Breaking Strength (lb/in.)		Elongation Ultimate (%)		Tear Strength (lb)		Adhesion	Abrasion Wyzen Peek 2,000 Cycles (% Loss) Break Strength	Temperature Resistance (^oF)		Hydrostatic Resistance[a] (psi)	Flame Resistance	Colorability	Puncture Resistance (lb)	Resistance to Mildew
			Warp	Fill	Warp	Fill	Warp	Fill			High	Low					
Herculite PVC/ Nylon Laminate	21	NA[b]	325	310	29	35	110	100	17.5	1.5	190	-20	510	yes	good	NA	yes
Clean Water Calendered Nitrile Rubber/ Nylon	60	NA	600	600	NA	NA	50	50	50	NA	NA	-30	NA	NA	NA	NA	yes
Shelter Rite 7128 Coated (PVC/polyester)	28	NA	717	NA	NA	NA	275		10	NA	NA	-40	500	yes	good	NA	yes
Shelter Rite 8420 (PVC/ Polyester)	20	NA	375	325	NA	NA	190	190	10	NA	NA	-40	500	yes	good	NA	yes
Burke Rubber Laminated (3 Ply Hypalon/ 2 Ply Nylon)	32	0.030	75	75	fabric 23	NA	NA	NA	NA	NA	NA	-45	NA	yes	good	130	yes
Hypalon-Neoprene Laminated Nylon	16.5	0.020	450	400	NA	NA	55	50	20	NA	NA	-40	750	NA	fair	NA	NA
Goodyear Polyliner Chlorinated Polyethylene/ Polyester	29-32	0.030	285	260	NA	NA	30	NA	20-40	NA	NA	NA	270-300	NA	NA	NA	NA
PVC/Nylon	22	NA	430	420	NA	NA	NA	NA	10	NA	NA	-65	440	yes	good	NA	NA
Polyurethane/ Unreinforced (Adiprene-Polyether Base)	NA	0.112	450		440		NA	NA	NA	NA	200	-80	NA	NA	good	NA	yes
Modified PVC/ Polyester	26-28	NA	412	350	40	40	139	150	NA	NA	NA	-20	400	NA	good	NA	yes
Polyurethane/ Polyester	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	good	NA	NA

[a] Liquid penetration.
[b] NA – not available.

Repairability is a measure of the capability of a material to have punctures and tears patched in the field: a function of the ease with which the adhesive is used, the time required for the bond to set up, and the strength developed by the bond. All of the materials in Table 4 can be repaired with an adhesive, solvent-welded, or heat-sealed. Since data were not available to permit comparison between coatings this property was not included in Table 4.

While nearly all fabrics listed claim to have resistance to rot and mildew, and some were indicated as meeting related MIL SPECS, no measure of this property was provided to allow comparison. Some coated fabrics are inherently resistant to attack by microorganisms, whereas others are specially formulated to resist attack. Also, prevention of marine growth can be accomplished by including antifouling compounds in the coating formulation. The desirability of this is questionable since these compounds work by leaching from the coating into the water and may themselves cause a pollution problem. Work currently being conducted at the Naval Ship Research and Development Center with antifouling coatings having reduced pollution potential may have future beneficial application for oil spill containment booms [31].

All listed materials claimed to be flame-resistant, and all possessed acceptable colorability.

All fabrics for which data were available seemed to satisfactorily resist the absorption of water as indicated by the high hydrostatic resistance. The Hypalon/neoprene/nylon composite showed the highest, and the chlorinated polyethylene the lowest, hydrostatic resistance.

The low temperature characteristics of all the materials was satisfactory, but sufficient data were not available to compare high temperature characteristics.

Although abrasion resistance data were available on most materials, the type of tests and manner of reporting the data were not uniform. Only those indicating abrasion resistance in terms of the Wyzenbeck method using 80-grit garnet paper for 2,000 cycles and expressing results in terms of breaking strength were included in Table 4. It should be noted that, while no comparison data are presented, the literature indicates that the abrasion resistance of polyurethane to be approximately eight times better than that of other plastic coatings [23].

Adhesion, as mentioned earlier, is inversely related to tear strength for a given fabric. The data presented in Table 4 express adhesion capacity in pounds determined in accordance with FTMS 191 Method 5970. To avoid conflicting statements, no quantitative value has been established in the boom specification for adhesion. Rather, the specifications require an 80% retention in adhesive capacity after a fresh water immersion test. Therefore, no comparison of the listed material can be made in terms of this property.

The only fabric listed in Table 4 for which data are available that meets the tear strength requirement of 200 pounds is the Shelter Rite 7128 (PVC/polyester).

Although no value has been established for the allowable or required elongation of the materials, the unreinforced polyurethane would probably elongate excessively and be detrimental to its performance as containment boom.

Based on the data available, the Shelter Rite 7128 and the nitrile rubber fabric have the highest breaking strength. However, the Shelter Rite material achieves this strength with considerably less material weight. It is anticipated that the polyurethane/polyester combination will exhibit similarly good strength to weight characteristics.

CONCLUSIONS

1. Although certain containment boom material requirements such as breaking strength are dependent somewhat on the particular boom design, for the most part, the properties required in boom materials apply universally to all booms intended for in-harbor use.

2. For coated fabrics, the mechanical properties of breaking strength, elongation, flexibility, and tear resistance are functions of the woven fabric substrate.

3. The fabric weaving technique, as well as the inherent properties of the yarn, determines the mechanical characteristics of the fabric.

4. The physical and chemical resistive properties of a coated fabric are primarily determined by the coating material and its thickness.

5. The lamination method of coating fabrics does not result in the substrate yarns being as well encapsulated or chemically tied to the coating and is, therefore, not as desirable as the knife edge, dip, or calendering methods.

6. A coating containing no plasticizer can be expected to maintain its properties over a longer period of time than one with plasticizers.

7. The substrate material exhibiting the most desirable characteristics for use in containment boom is polyester, followed by nylon.

8. The coating materials exhibiting the most desirable characteristics are chlorosulfonated polyethylene, polyurethane with a polyether base, chlorinated polyethylene, and PVC (when properly formulated to resist ultraviolet light degradation).

9. The large variations in material properties afforded by changes in coating formulations, weaving techniques, and processing methods prevent the identification of one combination of substrate and coating as the best for use in containment booms.

10. Standard test procedures do not exist for all of the defined requirements making it impossible to establish quantitatively the capability of candidate materials to meet these requirements.

11. For properties where adequate test methods exist, sufficient data are not available on candidate materials to permit a numerical evaluation using the weighted requirements. Where test data are available, comparison is hampered by variations in procedures and conditions under which the data were obtained.

RECOMMENDATIONS

1. Standard tests should be developed for those containment boom material requirements for which none exist.

2. A test program should be initiated to collect the data needed to perform a quantitative evaluation and comparison of the most promising boom materials in terms of the defined requirements.

3. Minimum acceptable values for all containment boom material requirements should be established and included in boom specifications.

4. The procurement specifications for oil spill containment booms should identify material requirements and require that data substantiating the capability of the material to meet the requirements, obtained through performance of the standard tests, be provided by prospective boom suppliers.

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